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Comparison between Dipole-dipole and Pole-dipole Arrays in Delineation of Subsurface Weak Zones Using 2D Electrical Imaging Technique in Al-Anbar University, Western Iraq

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Abstract

The presence of natural voids and fractures (weak zones) in subsurface gypsiferous soil and gypsum, within the University of Al-Anbar, western Iraq. It causes a harsher problem for civil engineering projects. Electrical resistivity technique is applied as an economic decipher for investigation underground weak zones. The inverse models of the Dipole-dipole and Pole-dipole arrays with a-spacing of 2 m and an n-factor of 6 clearly show that the resistivity contrast between the anomalous part of the weak zone and the background. The maximum thickness and shape are well defined from 2D imaging with Dipole-dipole array, the maximum thickness ranges between 9.5 to 11.5 m. It is concluded that the 2D imaging survey is a useful technique and more effective for determining and mapping subsurface weak zones (voids, fracture and cavities), when taken in consideration using the suitable a-spacing and n-factor for each electrode array, especially with the Dipole-dipole array which provided the best imaging of the subsurface shape of the weak zones.

Keywords: Pole-dipole array, Dipole-dipole array, Cavity detection, Weak zone delineation, Injana Formation.

مقارنة بين ترتيبي ثنائي القطب – ثنائي القطب وأحادي القطب – ثنائي القطب في تحديد أنطقه الضعف التحت سطحية باستخدام تقنية التصوير الكهربائي ألثنائية الأبعاد في جامعة الأنبار، غرب العراق

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الخلاصه

إن وجود الفراغات والكسور الطبيعية في التربة الجبسية والجبس التحت سطحية، داخل جامعة الأنبار، غرب العراق. سيسبب اشد المشاكل للمشاريع العمرانية المدنية. لذا فأن تطبيق تقنية المقاومة الكهربائية كحل اقتصادي لتفحص الفراغات الموجودة تحت السطح وتحديد أنطقه الضعف. حيث يُظهر الموديل المعكوس لترتيب أحادي القطب – ثنائي القطب وترتيب ثنائي القطب – ثنائي القطب مع عامل 6 وبمسافة قطبية 2 متر التغاير الواضح للمقاومة النوعية بين شذوذات أنطقه الضعف والصخور المحيطة بها ولكن بدقة مختلفة

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في شكل وسمك النطاق. أمكن التعرف على سمك وشكل الفراغات والكسور بشكل جيد من خلال التصوير الثنائي الأبعاد باستخدام ترتيب ثنائي القطب – ثنائي القطب، حيث يتراوح سمكها بين 9.5 و11.5 متر. استنتج بأن تقنية التصوير ثنائي البعد جيدة ومفيدة وأكثر فعالية لحساب ورسم خرائط الفجوات والكسور والكهوف التحت سطحية عند أستخدام فاصلة قطبية وعامل (n) ملائمين للنشر المعتمد وبخاصة في ترتيب ثنائي القطب – ثنائي القطب.

Introduction:

The subsurface voids, fractures, cavities and subsidence are natural phenomena that can occur in shallow geology sediments at different regions in the world. Cavities hazard assessment is one of the most difficult near subsurface investigations. It is clear that sinkhole formation is a dynamic process occurring over time, resulting in variations in the subsurface properties, such as porosity, fracture density, water saturation, etc. Roads and highway subsidence, building foundation collapse, and dam leakage are few of the problems related with cavities and sinkholes [1, 2]. In the Southern part of Al-Jazeera, along the left bank of the Euphrates River (West Iraq), large caves are formed in gypsum beds of Fatha Formation and carbonate rock of Euphrates Formation. Few kilometers north of Hit a large cave is formed in the gypsum beds of the plateau that border Euphrates valley. The altitude of the entrance of the cave is about 130 m A.S.L The presence of natural voids and fractures in subsurface gypsiferous soil and gypsum, within Al-Anbar University causes a harsher problem for civil engineering. The electrical resistivity technique is applied as an economic decipher for investigation underground voids and weak zone.

Selecting the correct geophysical tool for the detection of subsurface cavities and voids is not always straightforward, is of necessary importance in land-use planning [2]. The electrical resistivity method is considered as one of the promising geophysical methods that are used in the subsurface investigation because it gives a semi-true subsurface picture for buried structures with rapidity to calculate and determined the distribution of subsurface resistivity by making measurements on the ground surface [3, 4]. In Dipole-dipole array, the spacing between current and potential electrodes ($a-$spacing) are the same and remaining fixed for each spacing and n-factor [5]. Pole-dipole is another array that is using in shallow weak zones detection that has an approximately good in horizontal coverage and it is not sensitive to the telluric noise signal [6, 7]. Compared with the Dipole-dipole array that gives good sensitivity to telluric noise signal and it has higher signal strength [8]. The Pole-dipole array consist of four electrodes two current electrodes (A and B) and two potential electrodes (M and N), in a straight line fixed on the ground surface, the final current electrode (B) fixed far from the configuration about five to ten times of the depth penetration at an effective infinity distance from the array [9]. The Pole-dipole array is alike to the Dipole-dipole array; however, the Pole-dipole array is used when the survey penetration needs to acquire deeper [6].

Here are some previous studies in Iraq that used resistivity technique for identifying subsurface cavities, such as Al-Ane [10] that used Wenner array to detect the cavities in Hamam Al-Allele area, north Iraq. The resistivity map was drawn, and displayed high positive anomalies, where the cavities were present within gypsum rocks. Al-Gabery [11] measured two sounding stations, one over the known cave in the Rawa area, western Iraq, and the other is carried out at a distance of 80 m west of the cave using Wenner and Schlumberger arrays. In addition, twelve parallel profiles, along with each profile the resistivity measurements were carried out using Wenner, Schlumberger, and Pole-dipole (Bristow's method) arrays. The best result was acquired from the Pole-dipole array using the graphical Bristow method. Abed [12] compared between the two-dimension (2D) imaging resistivity survey and Bristow's method in detecting the accurate depth and shape of subsurface cavities, which is sited within Haditha-Hit area, western Iraq. The 2D imaging resistivity surveys are done along four traverses in Hit area, western Iraq. Dipole-dipole (n-factor = 6 and 8), Wenner-Schlumberger (n-factor = 8), and Pole-dipole (n-factor = 8) arrays are applied along traverse above Um El-Githoaa cavity. Another Dipole-dipole (n-factor = 6) array is carried out along a traverse in Haditha area overhead Wadhaha-Shamut cavity.

Graphical Bristow's method is based upon direct interpretation techniques that was measured with a potential electrode spacing of 2 m above the same traverse. Graphical Bristow's method and 2D imaging resistivity surveys are proved able to detect and distinguish subsurface cavities and voids. Thabit et. al., [13] used a 3D resistivity imaging survey, which was carried out over the Um El-

Githoaa cavity in Hit area, western Iraq. Resistivity data were collected along four parallel traverses using Dipole-dipole array with an electrode spacing of 2 m and n-factor = 6. Inverted 3D models obtained from the standard least-squares method and robust constrain method at Um El-Githoaa cave showed horizontal slices of the 3D resistivity distribution with depth. The comparison between the two methods of inversion appeared that the inverse model produced by the robust constrain method has sharper and straighter boundaries. Abed [14] used Graphical Bristow's method across K-3 cave to evaluate the method to detect the dimension of a relatively large natural cave. The data interpretation detects the cavity elongate along West-East traverse of about 58.6 m with an error not exceeded 3% in depth and 2% in height. Whereas Abed and Thabit [15] conducted a 2D imaging resistivity survey across an unknown K-3 cavity that is located in the Haditha area-Western Iraq. 2D measurements are collected along two intercrossing traverses above the cavity with a 105 m length of each one. Dipole-dipole array is performed with n-factor of 6 and a-spacing equals to 5 m. The K-3 cavity is well defined from the 2D imaging resistivity survey with selected Dipole-dipole array in comparison with the actual depth of this cavity, which equals to 11.5 m approximately.

The main objective is to compare between 2D imaging of Dipole-dipole and Pole-dipole electrode arrays survey in delineating the subsurface weak zone due to fracturing, weathering to support a subsurface of geologic interpretation and to map the bedrock surface

Materials and Method:

Geography and Geology of Study Area:

The study area located in the south of the Al-Ramadi city within Al-Anbar University, Al-Anbar province, western of Iraq. It is located between 33° 24' 7.13" N (Latitude) and 43° 15' 38.20" E (Longitude), (Fig. 1). The tectonic framework of the study area is lies within the Salman Zone of the Stable Shelf of Nubian-Arabian Platform from the west of Mesopotamian Zone (Euphrates Subzone) of the Unstable Shelf from the east [16]. Stratigraphically, the study area is within Injana Formation (Upper Fars Formation) which is consists of Gypsiferous Soil, Gypcrete, Pale brown claystone, Pinkish pale claystone, siltstone, and fine sandstone in cadenced nature. The thickness of the formation in the north of the Euphrates River reaches 18 m, while the southern part of the Euphrates River ranges from 5-8 m. The lower contact of the Injana Formation with the Fatha Formation is gradational [17].

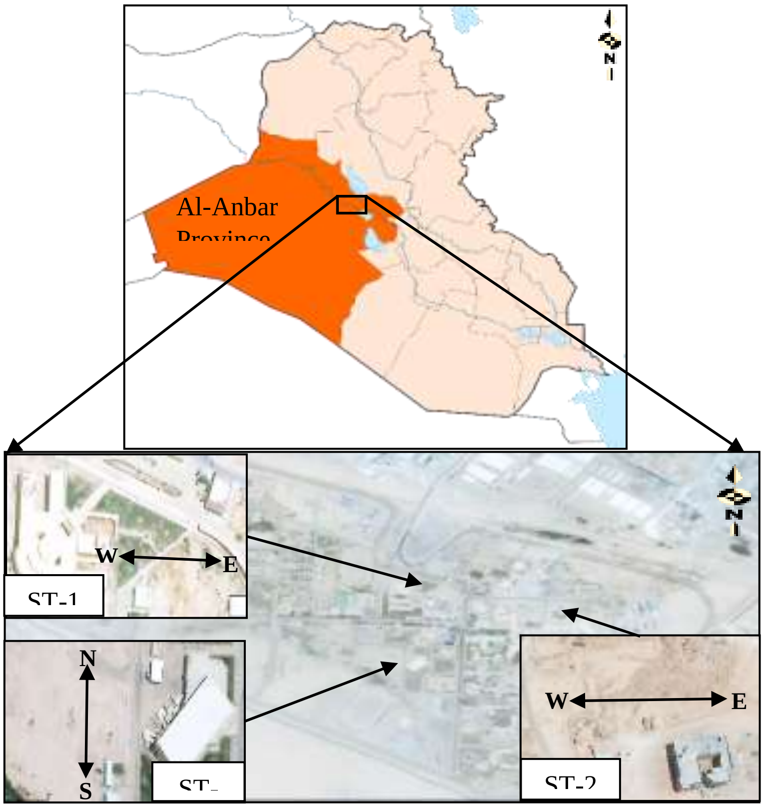


Figure 1- A satellite image shows the location of the study area within the three selected

Fieldwork:

The fieldwork was carried out in Al-Anbar University, with three stations (Table-1) were used to construct a 2D electrical image survey using Terrameter SAS-4000 instrument resistivity meter with 42 electrodes fixed straight line on the ground (Figure-2).

Table 1-Coordinates system of the measuring stations in the study area

Station ID	Latitude	Longitude	Elevation	Location of the Survey Line
ST-1	33˚ 24'14" N	43˚ 15'51" E	50 m	External garden for Faculty of Science.
ST-2	33˚ 24'13" N	43˚ 16'82" E	50 m	Near the Faculty of Literature.
ST-3	33˚ 24'20" N	43˚ 15'45" E	50 m	Near the University Presidency.

In the three stations, the Dipole-dipole and Pole-dipole survey have the same field parameters were the a-spacing of the electrodes is 2 m and n-factor of 6, the length of lines survey is 82 m and 58 m respectively.

All the measurements have been taken manually through moving the current and potential cables from one electrode to another; also, the recording of the data reading points was taken manually using the Microsoft Excel program, for preparing the data to process and interpretation using RES2DINV program.

After creating the sequence of field measurements using Electro-Pro software. The sequence of measurements depends on the type of survey, as well as the type of survey depends on several parameters which are; the number of electrodes, electrodes spacing (a-spacing), the type of array, n-factor and the depth of investigation want to be reached, finally taking the readings in the field. The field parameters and the number of data points of the three stations wherein, Table-2.

Table 2-The field parameters for each 2D survey line

Array type	a-spacing	No. of electrode	n-factor	Max. spacing	Level	Max. Of DOI.	No. of data points
Pole-dipole	2 m	30	1-6n	58.0 m	24	17.50 m	396
Dipole-dipole	2 m	42	1-6n	82.0 m	34	17.20 m	685

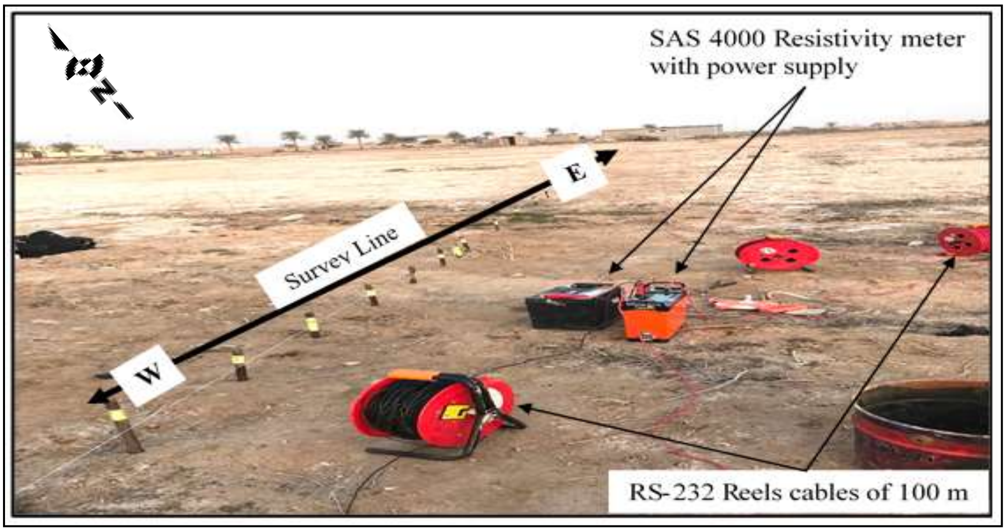


Figure 2- A sketch illustrations the 2D line survey and SAS Resistivity instruments at ST-2.

The field data were processed using the RES2DINV version 4.8.12 software package to create a 2D electrical image. RES2DINV is a computer software that will automatically design a two-dimensional resistivity profile for the subsurface resistivity distribution using the data that acquired from a 2D electrical survey [18, 19], after clean and removing the bad data in two stages which are; the first stage thru building a profile for data points and picks the bad data in manually mode (Figure-3A). The second stage is using the RMS error option to cut-off the bad data and improvements the total of the RMS error through automatic statically method through removing the data-points with a large percentage difference (Figure-3B). One advantage of this software is that the damping factor and anomalous part of the zone and background resistivity. flatness filters can be customary to suit altered types of field data [18, 19].

Inversion programs use mathematical algorithms to produce a subsurface resistivity model that will finest fit the apparent resistivity data set. To overcome the problem of non-uniqueness (many models fit the data equally well), the regularized least-squares optimization method is commonly used in the inversion algorithms. This method is dealing with the damping factor option, if the data reading is very noisy, a relatively larger damping factor (e.g. 0.3) is applied. If the data reading is less noisy, use a smaller initial damping factor (e.g. 0.1), as mentioned in [18]. Here, because of noisier data near the surface, a higher initial damping factor was used equals to 0.15, and a higher minimum damping factor equals to 0.02. Additionally, a higher damping factor was used for the first layer equals to 2.5.

The inversion subroutine will generally reduce the damping factor after each iteration. However, a minimum requires limit for the damping factor must be set to stabilizing the inversion process. The minimum value should usually set to about one-fifth of the value of the initial damping factor. Another important sub-option is the Vertical/Horizontal flatness filter ratio weight of one. If the main anomalies in the apparent resistivity pseudo section are elongated horizontally, it must choose a smaller weight than the vertical filter. Therefore, the flatness filter has used a weight of 0.5 [18].

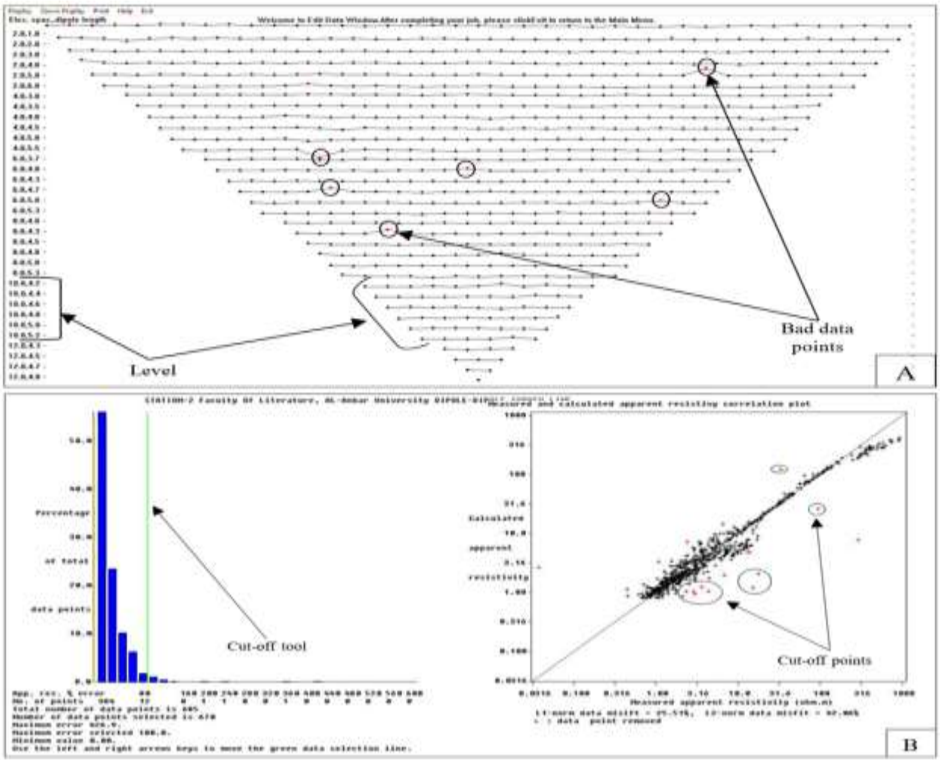


Figure 3- Field data set with a few bad data points of Dipole-dipole array traverse at ST-1; A) Picking the bad data in manually way. B) Automatic statically way through removing the data-point with large percentage difference.

Results and Discussion:

1- 2D Inverse of Dipole-dipole Data:

To generate the inverse model section of the true subsurface resistivity distribution, a starting model of the subsurface is used to calculate the distribution of apparent resistivity pseudo-section and compared with the apparent resistivity values measured in the field. The inversion results of 2D imaging of Dipole-dipole data along the traverse at ST-1 as shown in (Figure-4), it clearly indicates that the resistivity contrast between the anomalous part of the weak zone and background resistivity.

The inverse model produced by the Standard Least-Squares Method has a gradational boundary for the weak zone (Figure-4). The inverse model is the true image that is used for interpretation. The RMS error indicates how well the calculated pseudo section is fit to the measured pseudo section, so it is preferable to reduce it as much as possible. Nevertheless, in some cases, this is not true, especially if there is a high amount of geological noises, and the noise is usually more common with electrodes arrays such as Pole-dipole and Dipole-dipole arrays that have a very large geometric factor, and thus very small reading between potential electrodes [9]. From the inverse model (Figure-4), the maximum thickness of the weak zone appeared approximately equal to 11 m within the Injana Formation that is comprised of silty claystone interbedded with secondary gypsum and sandy loam. The RMS error is fairly high, equal to 16.4 percent of this model, which may be a result of near-surface inhomogeneity of dry sediments.

2- 2D Inverse of Pole-dipole Data:

The 2D inverse model of Pole-dipole for the subsurface weak zone is adjusted iteratively until the desired fit is achieved. The Figure-5 shows the inversion results of 2D inversion Pole-dipole data along traverse at stations ST-1, which clearly shows that the resistivity contrast between the

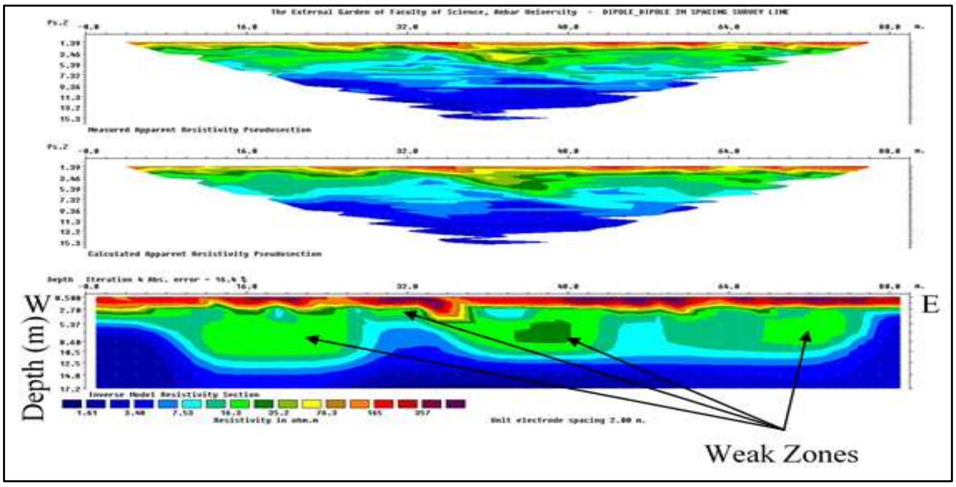


Figure 4- Measured and calculated pseudosections and inverse model of Dipole-dipole resistivity section along travers at ST-1 (Standard Least-Squares Inversion Method).

However, the anomaly of the weak zone, which appeared in the inverse model thickness of 9.7 m. It is smaller in comparison with the Dipole-dipole model, and the RMS error has a high value as a result of the large effect of noise [9], and as aforementioned of the 2D inverse of the Dipole-dipole array.

3- Comparison between Dipole-dipole and Pole-dipole Inverse Models:

The contours shape in the pseduosection formed by the different arrays over the same subsurface structure that can be very different. Figure-6 shows different arrays, Dipole-dipole, and Pole-dipole were used to map the same region that can give rise to very different contour shapes in the pseduosection scheme. Conversely, the pseduosection gives a distorted image of the subsurface since the shapes of the contours depend on the type of array used in addition to the true subsurface resistivity [9].

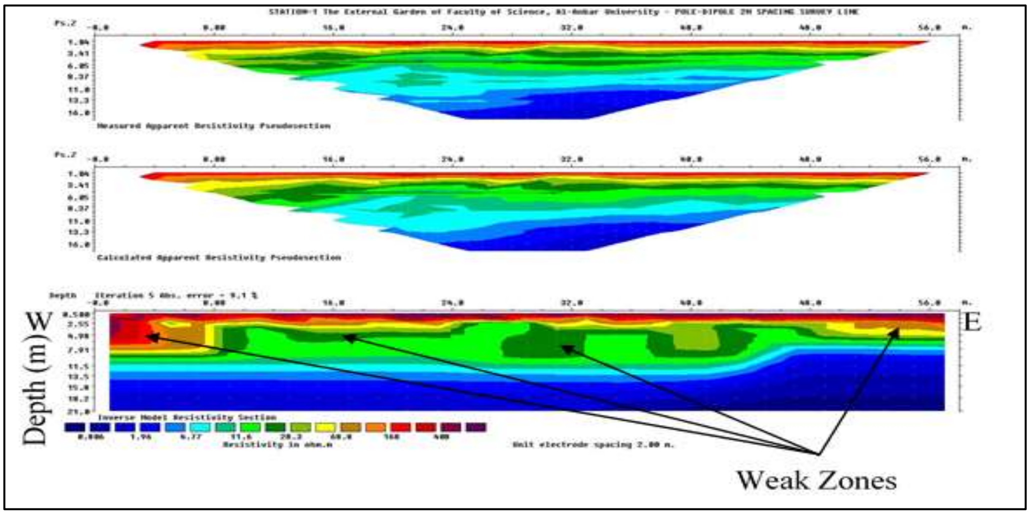
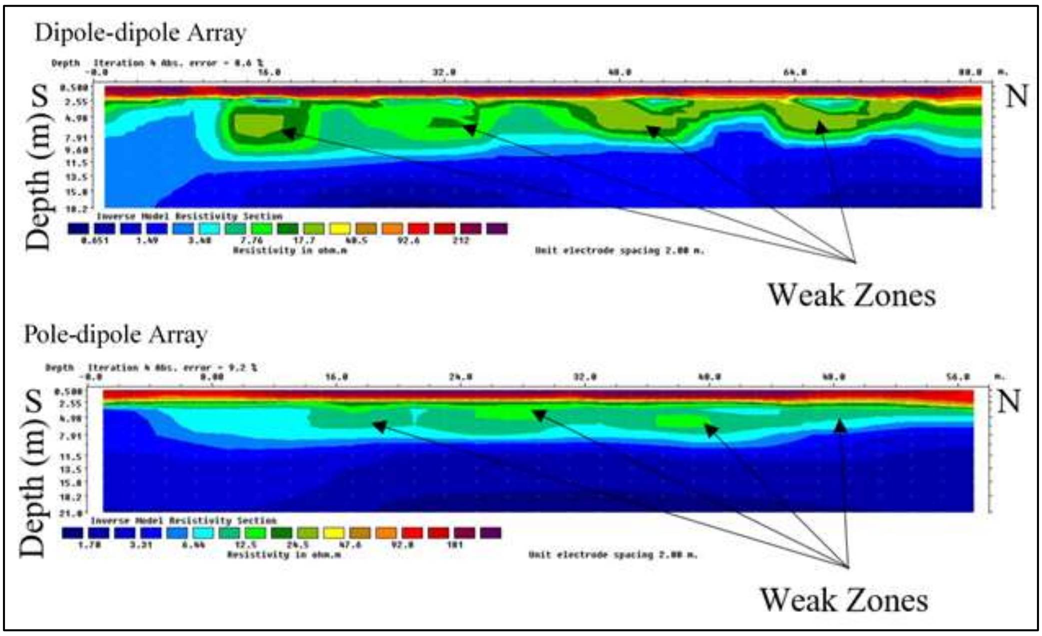


Figure 5- Measured and calculated pseudosections and inverse model of Pole-dipole resistivity section along travers at ST-1 (Standard Least-Squares Inversion Method).

Notes that the Dipole-dipole array provides the extensively horizontal coverage, while the coverage that is acquired through the Pole-dipole configuration decreases much more rapidly with increasing the spacing between the Pole-dipole electrodes [9].

As a result, the inverse models of 2D imaging survey from the Dipole-dipole and Pole-dipole arrays with a-spacing of 2m and n-factor of 6 respectively, along with three at ST-1, ST-2, and ST-3 have differed in the subsurface voids and fractures shape within the weak zones.



The inverse models show that all electrode arrays can be detecting the underground weak zones with different form and accuracy were the Dipole-dipole array provides the finest subsurface weak zones imaging Figures-(7, 8). The top section shows the measured resistivity pseudo section. The middle section shows the calculated apparent resistivity pseudo section based on the distribution of resistivity values in the inverse model, which is shown in the bottom section the underground weak

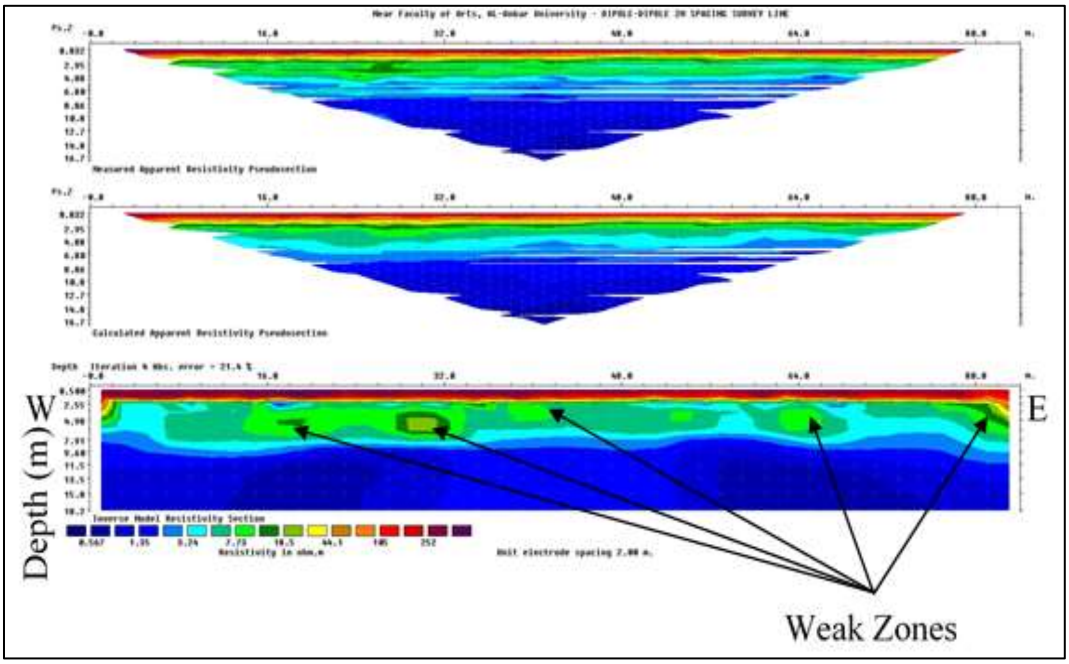


Figure 7- Measured and calculated pseudosections and inverse model of Dipole-dipole resistivity section along travers at ST-2 (Standard Least-Squares Inversion Method).

zone, which can be considered as a lateral anomaly in a homogenous medium. The thickness of the weak zone is well defined and ranges between 9.5 to 11.5 m through the 2D imaging with the Dipole-dipole array.

While the 2D inverse model of the Pole-dipole array for the subsurface weak zones is accustomed iteratively until the desired fit is succeeded. Figures-(9 and 10) show the inversion results of 2D inversion of Pole-dipole data along traverse which is clearly seen that the resistivity contrast between the anomalous part of the weak zone and the background resistivity.

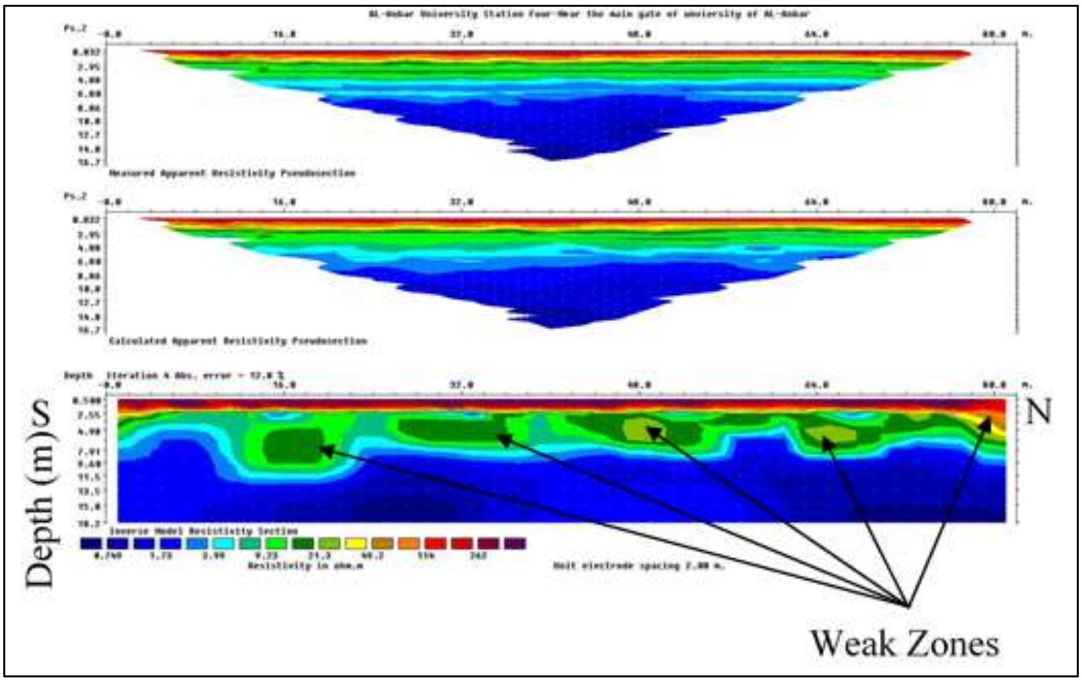


Figure 8- Measured and calculated pseudosections and inverse model of Dipole-dipole resistivity section along travers at ST-3 (Standard Least-Squares Inversion Method).

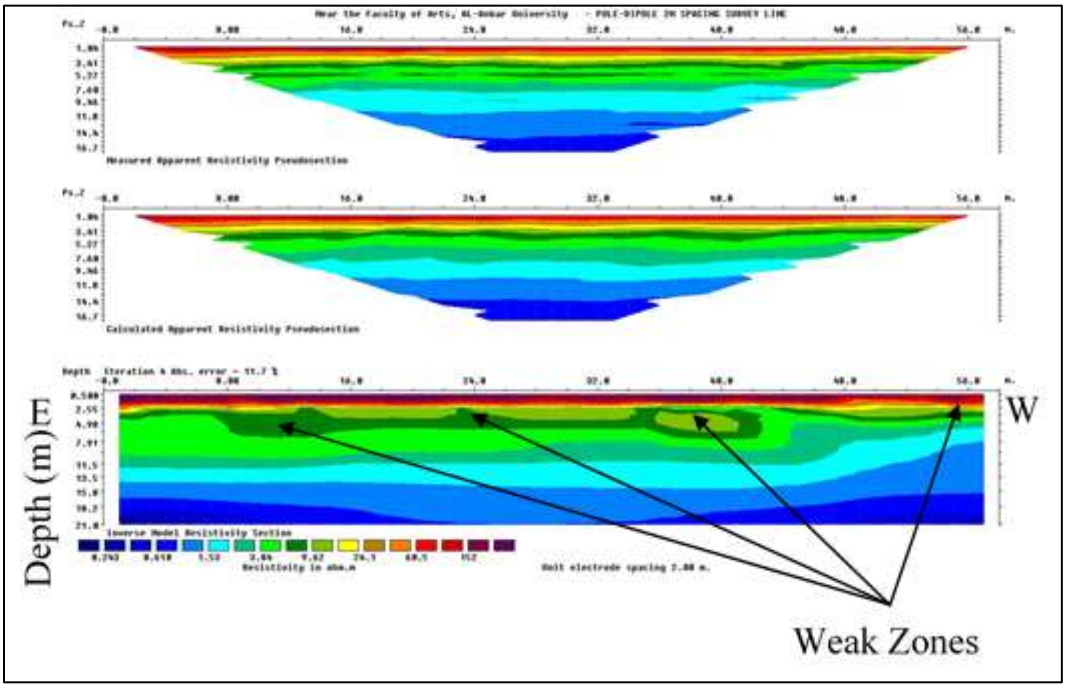


Figure 9- Measured and calculated pseudosections and inverse model of Pole-dipole resistivity section along travers at ST-2 (Standard Least-Squares Inversion Method).

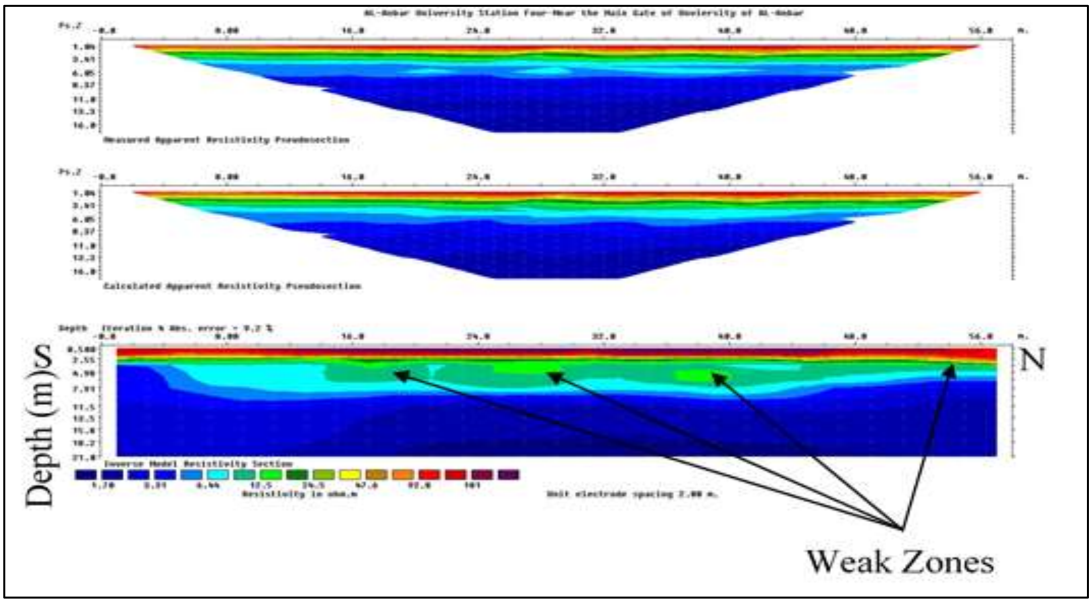


Figure 10- Measured and calculated pseudosections and inverse model of Pole-dipole resistivity section along travers at ST-3 (Standard Least-Squares Inversion Method).

Conclusions:

The inverse models of Dipole-dipole and Pole-dipole arrays with a-spacing of 2 m and n-factor of 6 clearly shows that the resistivity contrast between the anomalous part of the weak zones and the background. Consequently, the two types of electrode array can be detecting the underground weak zones but with different accuracy of the weak zones in the shape and thickness. The thickness and shape of voids and fractures are well defined from 2D imaging with the Dipole-dipole array, the thickness ranges between 9.5-11.5 m. The weak zone areas present within the Injana Formation that is characterized by the presence of silty claystone interbedded with secondary gypsum and sandy loam. It could be concluded that the 2D imaging survey is a useful technique and more operative for determining and mapping the subsurface weak zones (fractures and cavities) when taken in consideration using the suitable a-spacing and n-factor for each electrodes array, especially with the Dipole-dipole array which provides the best imaging of the subsurface weak zones.

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